CHARACTERIZATION OF WASTEWATER OF I.I.T. KANPUR
AND
STUDY OF THE EFFECT OF TEMPERATURE ON BOD RATE CONSTANT

A thesis submitted
in partial fulfilment of the requirements
for the Degree of
MASTER OF TECHNOLOGY IN CIVIL ENGINEERING

by

PRAKASH CHANDRA SACHAN

to the
Department of Civil Engineering
Indian Institute of Technology, Kanpur

July 1968

CERTIFICATE

This is to certify that this work on "Characterization of Wastewater of I.I.T. Kanpur and Study of the Effect of Temperature on BOD Rate Constant" has been carried out under my supervision and that this has not been submitted elsewhere for a degree.

R H Siddiqi

Dr.R.H. Sidiqi
Assistant Professor
Department of Civil Engineering
Indian Institute of Technology
Kanpur

TABLE OF CONTENTS

ABSTRACT

The study presents the results of characterization of wastewater from Hostel IV of Indian Institute of Technology, Kanpur. Among many determinations, two important parameters namely wastewater flow and BOD have been found to be 128 gallons per capita per day and 0.12 lb per capita per day respectively. The effect of temperature on BOD rate constant was also studied using Warburg respirometer and standard BOD technique. The rate constant was found to increase up to 35°C after which it started decreasing.

ACKNOWLEDGEMENT

The author wishes to gratefully acknowledge the valuable advice and encouragement of Dr. R.H. Sidiqi under whose guidence the work was carried out.

The author is also thankful to all colleagues and personnel of the Sanitary Engineering Laboratory who helped during the study.

This work was partially supported by a C.S.I.R. grant.

P.C. Sachan

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION AND SCOPE OF STUDY

India is getting industralized and urbanized at a rapid rate. With this an ever increasing volume of industrial and domestic wastes are being discharged. These wastes ultimately find their way in a natural water course. Any stream has a limited capacity to assimilate waste. Thus the discharge of untreated wastes in streams reduces its beneficial uses and endangers the health of communities using the water from these streams for domestic purposes. Use of such water requires costly treatment operations which could be minimized by a careful management of the waste initially.

To preserve the purity of water ways and to be able to suit the economic conditions of communities in India inexpensive and suitable sewage treatment methods should be evolved. For an intelligent design of waste treatment plant it is necessary to know the characterstics of the waste. In addition characterization is helpful in control and operation of treatment plant and evaluation of its efficiency. Very few studies regarding characterization of wastes have been carried out in India. It will be helpful to have more studies of this type to furnish realistic data to be able to plan and to base design of waste treatment facilities. In the present study waste water from Hostel IV of Indian Institute of Technology, Kanpur, has been analysed for its characterstics. The hostel accomodates about 450 persons. The waste water analysed is purely domestic in nature as it consists of waste water from the community mess, canteen, floor washings, bath rooms and water closets.

The biochemical oxygen demand, BOD, test is one of the important parameters to measure the strength of a waste. Also to observe the progression of decay of organic matter in a stream one should know the rate at which BOD is being exerted. According to standard practice the BOD of a waste and its rate constant are determined at 20°C, which is the mean stream temperature in U.S.A. and other European countries. The temperature of water in streams in India is higher and in the critical months of summer when the biological activity is maximum it may even be as high as 35°C. Since the stream temperature is bound to be different from the standard temperature at which BOD data is available, the relationship between values of BOD rate constants at different temperatures becomes important. Work has been done in this area by other workers in India (1),(2),(3). However, there is difference in the data reported as to the applicability of the standard relationship between BOD rate constants at different temperatures arrived at in other countries. In the present study the effect of temperature on BOD rate constant was also studied by using a Warburg respirometer as well as the standard BOD dilution method (4).

2. LITERATURE REVIEW

2.1 Parameters of Characterization

Number of parameters for characterization of waste water have been recommended (4). Those which were used in this study are mentioned below along with their significance.

Observation of temperature of wastewater is useful in indicating the solubility of gases in it and rate of biological activity. Temperature effects the viscosity of wastewater which in turn effects the efficiency of sedimentation. Normally in India the temperature of sewage is 1-2°C higher than the temperature of water supply. In United States the temperature of water supply is much lower (7-8°C), but due to usage of steam and hot water for domestic purposes the temperature of waste may be as high as 20°C. Temperatures of domestic wastewater varying from 16-20°C have been reported for United States(5). Exceptionally high temperature of wastewater indicates presence of hot industrial waste.

Determination of hydrogen ion concentration or pH is valuable mainly in controlling the operation of a sewage treatment plant. The pH of fresh domestic waste is slightly more than the water used. The increase in pH may be due to addition of compounds of ammonia and phosphates. Stale sewage becomes acidic innature. In the acidic range hydrogen sulfide gets oxidized to sulfuric acid, which may attack the material of the sewer pipes(6). pH value in the range of 7.5-8.0 have been reported for domestic wastes from various cities in India (7),(8).

Total solids in a waste are important as an index to its strength, the amount of treatment required and as a measure of the efficiency of a treatment device (9),(10). Solids are contributed to the domestic waste in the form of human wastes, kitchen washings, floor sweepings etc. Total solids may be divided in to suspended and dissolved solids fractions which may be further characterised as volatile and fixed or organic and inorganic respectively. Out of these volatile suspended and dissolved fractions are important because they are putrefactive and difficult to remove. Dissolved inorganic fraction becomes important if reuse of waste is planned as this fraction may have to be removed by chemical precipitation or other costly methods. Total solid content of the domestic waste in U.S.A. have been reported to be of the order of about 700 mg/l (11). In India studies have shown that it lies in the range of 1100-2200 mg/l (8),(12),(13),(14).

The chloride content of wastewater above the normal chloride content of water supply to a community is used as an index of the strength of waste. Human excreta, particularly urine, contains chloride in an amount nearly equal to the chlorides consumed with food and water. This amount averages about 8 grams of chloride per person per day. With an average per capita per day wastewater flow of 100 gallons, this should result in the chloride content of wastewater to be 15 mg/l higher than the water consumed (6). Studies for some Indian cities have reported the chloride content of domestic waste in the range of 85-300 mg/l (7),(8),(14). No values for the concentration in water supply was reported.

The principal nitrogenous compounds in the waste are proteins and urea (11). Ammonia nitrogen is formed as a result of bacterial decomposition of proteinacious matter and urea. The total concentration of ammonia and organic nitrogen is a valuable index of the strength of wastewater and is important at times in the selection of type of treatment to be given. For an aerobic biological treatment system to operate satisfactorily a BOD:N ratio of 100:5 is necessary (15).

Studies in India have reported the value of ammonia nitrogen in the range of 12-24 mg/l (8),(14) and values of the order of 20-25 mg/l for albuminoid nitrogen which is generally half of the organic nitrogen (8),(12).

Phosphorous is contributed to the domestic waste by human waste [redacted] In addition to this source synthetic detergents contribute substantial amount of phosphorous. Organisms involved in biological processes of waste treatment require phosphorous for reproduction and synthesis of new cell tissues. Domestic wastewater contains amount of phosphorous far in excess of the amount needed for this purpose (6). For adequate nutrition of a biological process BOD:N:P ratio of 100:5:1 has been found satisfactory (15). Phosphorous content ranging from 3-8 mg/l has been reported for the waste waters from some Indian cities (8),(14).

Both nitrogen and phosphorous combined together are responsible for eutrophication in water bodies (16). Sawyer (17) has concluded that other conditions being suitable, any lake showing concentrations in excess of 0.01 ppm of inorganic phosphorous and 0.3 ppm of inorganic nitrogen at the time of spring overturn could be expected to produce

algal blooms of such density as to cause nuisance. Currently great effort is directed towards removal of these nutrients from waste streams.

The biochemical oxygen demand, BOD, of a wastewater is amount of oxygen required by microorganisms to oxidize the decomposable organic matter to carbon dioxide and other nonoxidisable stable end products under aerobic conditions. Since the decomposition by biological means may take a long time for its completion, it is customery to observe the oxygen demand up to five days. Further more as the biological reactions are affected by temperature, the standard BOD test measures the oxygen uptake at 20°C.

The rate of exertion of oxygen demand by microorganisms for decomposition of organic matter has been formulated in the form of a first order reaction as given below (11):

$$y_t = L_o(1-e^{-kt}) = L_o\ (1-10^{-Kt}) \quad \ldots\ldots\ldots\ldots 2.1.1$$?

where L_o is the oxygen demand of the waste initially, y_t is the oxygen demand exerted in time t, K and k are the BOD rate constants corresponding to common and natural logarithams respectively. The above formula is only an approximation as in practice the rate of oxidation is not constant and the value of K change with time. The reason being a heteroganeous nature of the organic matter and changing concentration and nature of biological life present in the wastewater during the period of experiment.

Number of methods have been suggested to determine the value of K from the observed values of y_t (18),(19),(20),(21). Out of these the one given by Fujimoto (20) has been used in the present study.

The method is explained in Appendix A.

The knowledge of BOD contribution per capita and BOD rate constant is important for an intelligent design of wastewater treatment facilities, prediction of equivalent population and control of pollution of water bodies. In U.S.A. a domestic wastewater is reported to have a 5 day, 20°C BOD ranging from 0.12 - 0.22 lb/cap/day with an average of about 0.17 lb/cap/day (2). In U.K. a 5 day, 20°C BOD value of 0.12 lb/cap/day has been reported by Bolton and Klein (23). In these countries the reported values of rate constant at 20°C, K_{20} lie between 0.16 - 0.3 per day (24),(25),(26). Studies carried out in India have reported a 5-day, 20°C value in the range of 0.06 - 0.1 lb/cap/day (2) and K_{20} values in the range of 0.12 - 0.17 per day (1),(2),(3).

Chemical oxygen demand, COD, test has been devised in an attempt to overcome the objections to the BOD test such as the time required for the test and uncertainties concerning the reaction rate constant K. The COD test involves chemical digestion of sample with an oxidizing agent. A corelation can be found between BOD and COD which could be used to predict the BOD values. However, this would be satisfactory only when the composition of wastewater is fairly constant.

The volume of wastewater and its hourly variation depends upon the population, type of community served, underground water conditions, season and time of concentration. The maximum and minimum rates of flow are the controlling factors in the design of sewers. The capacity of the sewers must be sufficient to carry the maximum load and they must be laid on such a slope that deposition will not occur during minimum flow.

The relationships between maximum, minimum andaverage flows have been expressed as fallows (22):

Maximum daily flow = 2 x Average daily flow 2.1.2

Minimum hourly flow= 1.5 x maximum daily flow

= 3 x average daily flow 2.1.3

$$\frac{Q_{max}}{Q_{ave}} = \frac{(18 + \sqrt{P})}{(4 + \sqrt{P})} \qquad \ldots\ldots\ldots\ldots 2.1.4$$

where Q_{max} and Q_{ave} are the maximum and average rates of flow respectively and P is the population in thousands.

In U.S.A. the wastewater flow has been reported in the range of 70 - 100 gal/cap/day (9),(11),(22). Arceivala and Gajendragadkar (2) have reported a wastewater flow of 27 gal/cap/day for a purely residential area of Bombay city. Same study has reported maximum hourly flow to be twice the average daily flow and minimum hourly flow to be one sixteenth of the average daily flow.

2.2 Effect of Temperature on BOD Rate Constant

The rates of most chemical reactions increase with increasing temperature. The change in specific rate constant with change of temperature for any simple chemical reaction is usually expressed by Arrheneous equation (22). This equation states:

$$\frac{d\,(\ln k)}{dT} = \frac{E}{RT^2} \qquad \ldots\ldots\ldots\ldots 2.2.1$$

where k is the specific reaction rate constant, T is the absolute temperature, R is the gas constant and E is a constant characterstic of the reaction and is also termed as the activiation energy. Integration of the above equation between the limits T_1 and T_2 and simplification yields:

$$\frac{k_2}{k_1} = e^{\alpha} \qquad \ldots\ldots\ldots\ldots 2.2.2.$$

where

$$\alpha = \frac{E(T_2 - T_1)}{RT_1 \; T_2}$$ and k_1 and k_2 are rate constants at temperature T_1 and T_2 respectively.

Considering a small temperature range encountered during BOD study the product of T_1 and T_2 will be nearly constant. Therefore can be equated to $A(T_2-T_1)$ where A is a constant. Hence equation (2.2.2) can be rewritten as:

$$\frac{k_2}{k_1} = e^{A(T_2 - T_1)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.2.3$$

or

$$\frac{K_2}{K_1} = \emptyset^{\,T_2 - T_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.2.4$$

where K_1 and K_2 are rate constants corresponding to common logaritham at temperatures T_1 and T_2 respectively.

Number of workers have studied the effect of temperature on rate constant. Streeter and Phelps (29) deduced the relationship between rate constant and temparature as follows:

$$K_T = K_{20} \times 1.047^{T-20} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.2.5$$

where K_T and K_{20} are rate constants at temperatures T and 20°C respectively.

According to them the above is valid in the range of 2 - 40°C. The above work was confirmed by Theriault (30). However, Gotaas (24) postulated different equations for different ranges of temperature. His findings are given below:

for 5-15°C, $K_T = K_{20} \times 1.108^{T-20}$ 2.2.6

for 15-40°C, $K_T = K_{20} \times 1.041^{T-20}$ 2.2.7

for 30-40°C, $K_T = K_{20} \; (.965)^{T-20}$ 2.2.8

Arceivala and Gajendragadkar (2) using the relationship given by Phelps (29) reported that the rate constant increased with increasing temperature upto a maximum of 30°C. While Bewtra and Radhacharan (1) found the rate constant starts decreasing after 37°C.

For many years the dilution method (4) has been the standard test to measure the BOD of a wastewater, even though many objections have been raised by its users (31),(32),(33),(34),(35),(36),(37).

Some of these objections are that the dilution method uses a small waste sample volume, hence decreasing the probability of a representative sample. Several dilutions of the unknown sample must be made since the oxygen demand of the sample can not exceed the solubility of oxygen in dilution water. Manometric methods of observing oxygen uptake are free from above objections (39). In this method one observes physical change in the system and the sample is not disturbed. The manometric method is specially well suited for the study of reaction rates since the variables are subjected to better control and readings at small intervals of time may be taken without disturbing the sample (34).

In the present study Warburg respirometer was used to determine

the effect of temperature on BOD rate constant. In this method the oxygen uptake in mg/l is given by the following equation (38):

$$w = Kh \qquad \ldots\ldots\ldots\ldots\ldots\ldots \; 2.2.9$$

where w is oxygen uptake in mg/l, h is the change in manometric head and K is a constant which is determined for a flask, sample volume, temperature K is given by the following relationship:

$$K = \left[\frac{273V_g}{TP_o} + \frac{V_f\alpha}{P_o}\right] \frac{1430}{V_f} \qquad \ldots\ldots\ldots \; 2.2.10$$

where V_g is the total volume of the gas in the flask, connecting tube and manometer to the level of manometer fluid reference point, T is the absolute temperature of the bath, P_o is the normal pressure in cm of Brodie's solution which is 1000 cm, α is the volume of oxygen in ml at N.T.P. absorbed by one ml of water at the temperature T when pressure of dry gas is 760 mm of mercury and V_f is volume of fluid in ml.

Tool (39) studied manometrically the effect of temperature on BOD rate constant and found out that the reaction rate constant at 35°C was double than at 20°C.

3. EXPERIMENTAL METHODS

The wastewater characterized in the present study was from Hostel IV of Indian Institute of Technology, Kanpur. There are about 400 students in the hostel and 50 mess servents living in the dormitory attached to the hostel. Thus the wastewater from the hostel consists of waste from bath rooms, water closets, kitchen washings and floor sweepings.

3.1 Characterization of Wastewater

In order that study of characterization be meaningful collection of representative samples is necessary. Samples must be first carefully collected over the time period under study and then composited. Different steps involved in the subsequent analysis are described in the following sections.

3.1.1 Sampling

Samples were collected every hour over a twenty four hour period and composited on the basis of flow. In all five such composite samples were collected on different weekdays. The minimum sample volume based on flow was 120 ml as specified in Standard Methods (4). The hourly samples were stored at 3 - 4°C untill they were composited.

3.1.2 Flow Measurement

The wastewater collection and treatment system for Hostel IV is shown in Figure 1. The combined waste from various units in the hostel flows through manhole A. Samples were collected from this manhole. From the manhole wastewater flows to a septic tank through a 9" sewer line. From septic tank the wastewater is periodically pumped out by a pump and discharged over nearby fields.

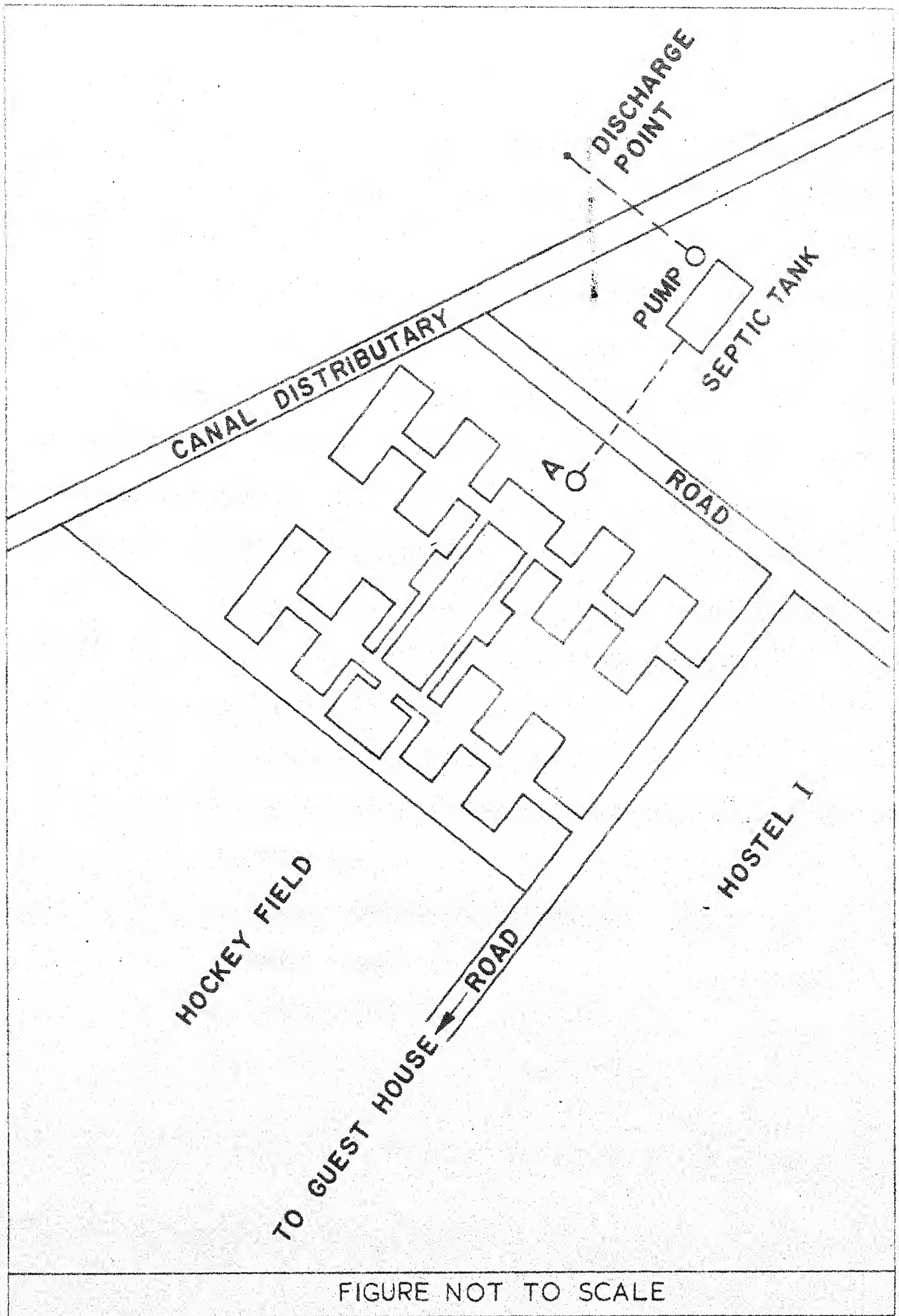


FIG. I SITE PLAN OF HOSTEL IV AND WASTE DISPOSAL SYSTEM

The total flow in any time period was calculated by equating it to the sum of amount pumped and that stored in the septic tank within that interval. The discharge of pump was determined with the help of a V notch and also by using a dye. The dye was introduced at the suction end of the pump and its time of appearence at the outlet of the delivery pipe was noted. The discharge of the pump was calculated using the length of pipe, its diameter and the observed time of flow. It was found to be 10000 gph. Knowing the floor area of the septic tank storage was determined by noting the level of the waste water in the tank. Depending upon pumping hours and waste flow the storage was either positive on negative.

3.1.3 Analysis of Samples

Each composite sample was analyzed in triplicate according to Standard Methods (4) for the following characteristics:

a. Temperature.

b. Hydrogen ion concentration.

c. Total solids: dissolved, suspended, volatile and fixed fraction.

d. Chlorides.

e. Ammonia and Organic Nitrogen.

f. Total Phosphate.

g. Chemical Oxygen Demand, COD.

h. Biochemical Oxygen Demand, BOD.

For the determination of BOD in all the experiments a 2% dilution of the waste was used. This figure was arrived at by making some preliminary studies.

3.2 Effect of Temperature on BOD Rateconstant

Temperature effect on BOD rate constant was determined by dilution

and Warburg method.

3.2.1 Study by Conventional Method

The BOD of five composite samples was determined at different temperatures shown in column 3 of Table 1.

TABLE 1

DATES ON WHICH SAMPLES WERE COLLECTED AND RESPECTIVE TEMPERATURES OF INCUBATION FOR BOD DETERMINATION

Sample No.	Date of Collection	Temperature of Incubation for BOD Determination °C
(1)	(2)	(3)
1	21.9.67	30
2	10.10.67	40
3	12.10.67	20
4	18.10.67	10
5	21.10.67	45

In addition to that each sample was analyzed for BOD at 35°C. This was done with a view to see if there was a change in characteristic of the waste on the five different occassions that it was sampled. Any change would have resulted in a significant variation of the rate constant at 35°C. In such a case the difference between the values of rate constants at other temperatures would not have been due to only a difference of temperature. To determine the rate constants oxygen consumed was determined every day for a period of six days. For each observation triplicate samples were analyzed.

3.2.2 Study by Warburg Respirometer

This part of the study was carried out with grab samples of wastewater from the hostel. Oxygen uptake by the samples was determined according to method described in Standard Methad (38). The uptako was determined at 20,25,30,35,40 and 45°C over a period of 24 hours. For each temperature triplicate samples were analyzed.

4. RESULTS AND DISCUSSION

4.1 Flow Measurement

The hourly variation of flow on the five days on which samples were collected is shown in Figure 2. The figure also shows the average of these values. The number of residents on the five days of sampling varied from 432 to 462 with an average of 450. The average variation shown in the figure is not weighted according to population as the variation in population was small.

The per capita discharge from the data of Figure 2 was found to be 128 gpcd. It is seen that the average waste flow per capita per day is much higher than that assumed in Indian conditions which is about 30 gallons per capita per day (2),(7),(12),(13),(40). The maximum and minimum hourly flows occured at 7.30 A.M. and 3 A.M. respectively.

The reasons for high flow are a twenty four hour supply, maintenance of high pressures, leaks and automatic flushing of urinals through out the day. Contribution from the last two factors mentioned above can be estimated from the flow during the late hours of night. This is of the order of 1500 gph. This amounts to about 80 gpcd. Taking this into account the wastewater flow reduces to only 48 gpcd. A high wastewater flow can be indicative of efficient and liberal water supply, but also an excessive wastage. The wastage not only adversely effects the sewerage and pumping system but taxes the water supply system also. The peak at 7.30 A.M. is due to high usage of water for bathing and flushing etc in the morning hours.

From the variation of flow shown in Figure 2 the ratios of maximum and minimum hourly flows to the average flow are found to be 1.8 and 1.6

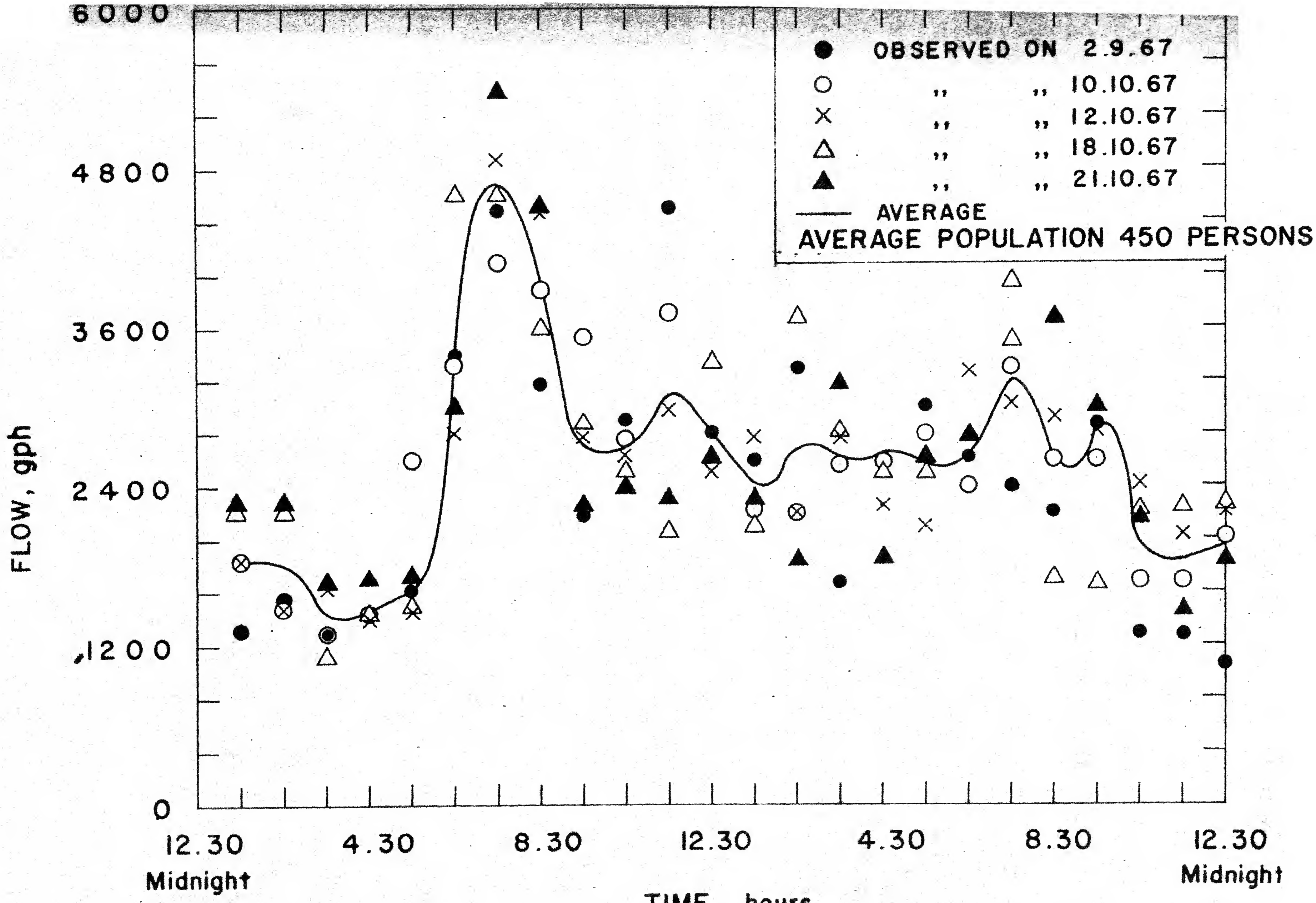


FIG. 2 HOURLY VARIATION OF WASTEWATER FLOW

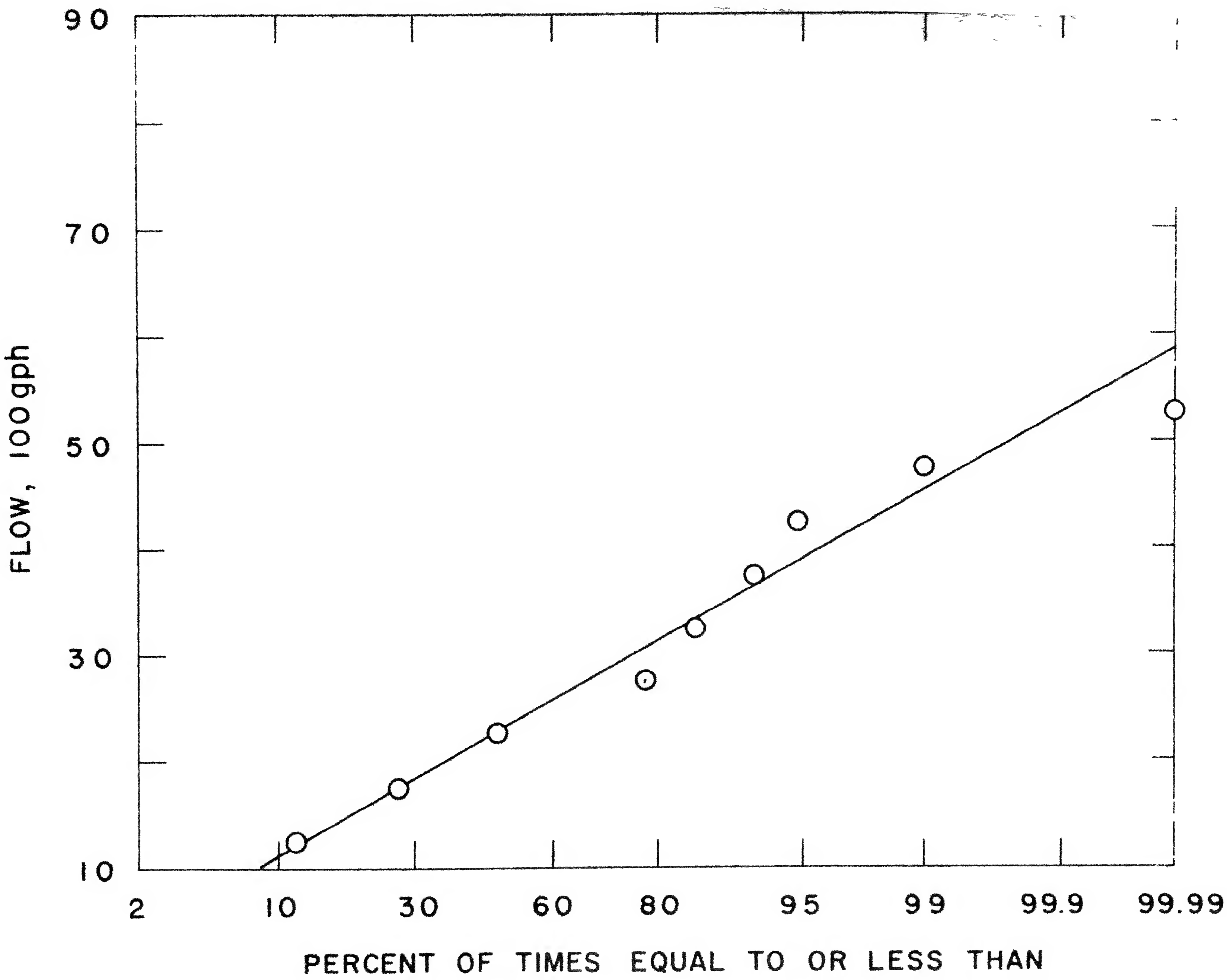
respectively. While the ratio of maximum to average is in conformity of the values reported in chapter 2, the ratio of minimum to average is considerably high. This again indicates a constant wastage.

Table 2 shows the statistical analysis of wastewater flow data. This has been plotted on arithmatic probability paper in Figure 3.

TABLE 2

FREQUENCY TABLE FOR V LUME OF WASTEWATER GENERATED EACH HOUR

Volume	Occurences						Percent Cumulative Frequency
100 gph	21.9.67	10.10.67	12.10.67	18.10.67	21.10.67	Total	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0-10	-	-	-	-	-	-	0
10.1-15	5	3	3	3	-	14	11.7
15.1-20	5	3	2	1	7	18	26.8
20.1-25	2	4	6	7	6	25	47.5
25.1-30	6	8	10	7	6	37	78.0
30.1-35	3	2	1	1	1	8	85
35.1-40	0	3	-	3	2	8	91.5
40.1-45	3	1	1	2	1	8	98.5
45.1-50	-	-	1	-	-	1	99
51.1-55	-	-	-	-	1	1	99.99
Total	24	24	24	24	24	120	



DISTRIBUTION OF HOURLY WASTEWATER FLOWS

The importance of the statistical analysis lies in the fact that it provides the basis for assignment of process and hydraulic flows. Process design criteria are usually based on 50 percent values while the 90 percent to 99 percent range is used for the hydraulic design (15). In the present case 95 percent of times the discharge is equal to or less than 4000 gph. This value is quite close to the maximum flow observed.

4.2 Analysis of Samples

The composited sample was analysed for various characterstics and constituents as listed in Chapter 3. These results are summerized in Table 3.

The pH of the water supply to the hostel lies between 7.7-8.1 (41). It is seen from Table 3 that there is an increase of pH of water when it is used. Thiscould be due to opportunity for dissolved carbon dioxide to escape from water and also due to addition of compounds of ammonia, phosphate etc. These values are consistent with those reported in literature for domestic wastewater.

The temperature of water supply during the period of sample collection varied between 23-26°C, while the daily mean temperature of the wastewater on the days of sampling was between 28.5 - 29.5°C. This expected as the water absorbs heat during its usage.

The average total solid content of the wastewater is 752 mg/l. For some other Indian cities total solid content has been reported in the range of 1500-2200 mg/l (7),(8),(13),(14). The lower total solid content in the wastewater from the hostel is due to approximately three times more water consumption per capita than in other Indian cities. It is also seen that the volatile fraction is 33 percent of the total

CHARACTERSTICS OF WASTEWATER*

Characterstic	Date of Sample Collection					
	21.9.67	10.10.67	12.10.67	18.10.67	21.10.67	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)
pH	8.2	8.4	8.2	8.3	8.2	8.26
Temperature	29.5	29.0	29.0	29.0	28.5	29.0
Total Solids	860	710	740	642	769	752
Suspended solids						
(a) Fixed fraction	120	47	95	102	99	93
(b) Volatile fraction	20	13	24	12	25	19
Dissolved Solids						
(a) Fixed fraction	480	405	395	402	375	411
(b) Volatile fraction	240	245	226	166	270	230
Ammonia Nitrogen	4.4	3.9	4.9	3.4	5.3	4.4
Organic Nitrogen	9.6	6.7	8.3	7.8	7.3	7.9
Total Phosphate	-	3.2	3.3	3.1	5.0	3.7
Chlorides	35	60	52	54	66	53
COD	280	320	270	260	170	260
5-day, $35^{\circ}C$ BOD	189	218	182	186	110	177
Rate constant, $K_{35^{\circ}C}$	0.31	0.27	0.30	0.29	0.27	0.29
Rate constant, $K_{20^{\circ}C}$+	0.155	0.135	0.15	0.145	0.135	0.145
Ultimate, $20^{\circ}C$ BOD+	153	168	140	143	85	138
5-day, $20^{\circ}C$ BOD+	129	135	115	117	70	113

* All quantities are in mg/l except pH, temperature and rate constant which are in pH units, °C and per day respectively.

\+ Computed values from the observed data.

solids concentration

The chloride content of the campus water supply is about 40 mg/1 (41), whereas the chloride content for the wastewater has been found to be 53 mg/1. This shows that there is an increase of 13 mg/1 in the chloride content. It has been reported that due to human usage the chloride content of wastewater rises by about 15 mg/1(5). However this figure is dependent on daily per capita consumption of water.

Ammonia nitrogen content is much lower than the organic nitrrgen, indicating that decomposition of wastewater has not started. As compared to other studies quoted in Chapter 2 the values of ammonia and organic nitrogen content as shown in Table 3 are lower. The reason again is a high per capita consumption of water.

The concentration of phosphorous in the wastewater is 3.7 mg/1 which is of the same order as reported by other investigators. The concentration is sufficient for any treatment process to proceed satisfactorily (15).

The concentration of biodegradable organic matter as reflected by the 5-day, 20°C BOD value in the waste is that which would be expected in a domestic waste. The 5-day, 20°C BOD and ultimate, 20°C BOD as computed from the observed values at 35°C are 138 mg/1 and 113 mg/1 respectively. The rate constant at 20°C, K_{20} calculated from the observed data at 35°C is 0.145/day. This value is consistant with the values reported by others.

Figure 4 shows the relationship between COD and ultimate, 20°C BOD. It is seen that the ultimate, 20°C BOD of the wastewater

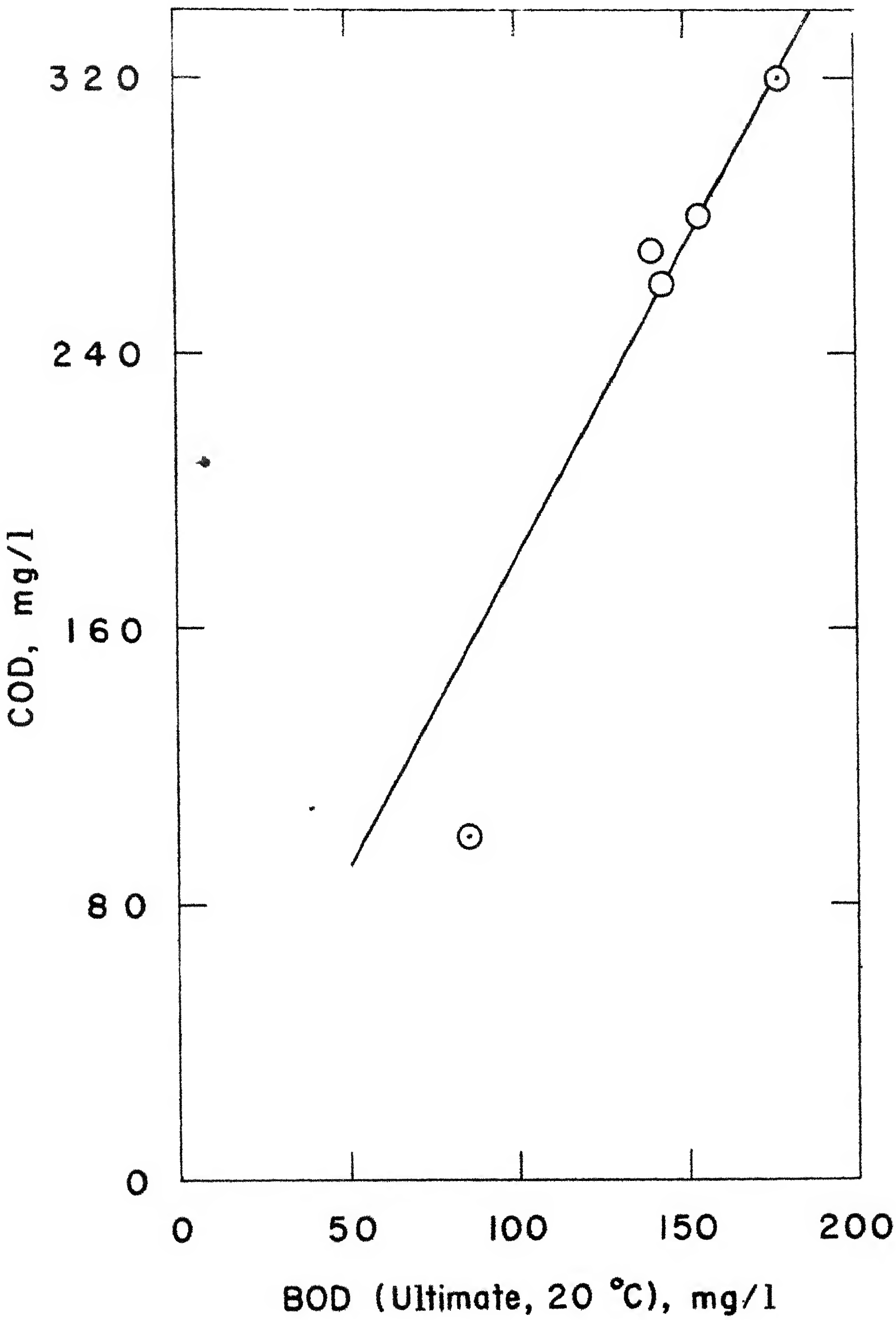


FIG. 4 RELATIONSHIP BETWEEN BOD AND COD

is about 56 percent of the COD value.

As it has been pointed out earlier the concentration of various impurities in wastewater depends upon the per capita consumption of water and also on their concentration in water supply. Therefore any waste characterization data will be more meaning ful if it is expressed on the basis of per capita contribution. This data can be used for the design of wastewater treatment systems for places having different water supply conditions. Table 4 shows such an analysis of the present data.

TABLE 4

DAILY PER CAPITA CONTRIBUTION OF WASTEWATER CONSTITUENTS

Characterstic	Water Supply mg/l	Wastewater mg/l	Difference of (3) and (2) mg/l	Contribution lbs/cap/day
(1)	(2)	(3)	(4)	(5)
Total Solids	600	752	152	0.16
Dissolved Solids	575	641	66	0.07
Suspended Solids	25	112	86	0.09
Ammonia Nitrogen	Nil	4.4	4.4	0.0047
Organic Nitrogen	Nil	7.9	7.9	0.0085
Total Phosphate	0.5	3.7	3.2	0.003
Chlorides	40	53	13	0.014
5-day, 20°C BOD	Nil	113	113	0.12

The value of daily per capita contribution of solids as compared to that reported by Fair and Geyer (22) is rather low. The reason for this may be due to the fact that the authors have not taken into account

concentration of substances in the water supply.

The value of daily per capita contribution of nitrogen is about half of the value reported for U.S.A. (11). The BOD to nitrogen ratio in the present case is approximately 100:15 as compared to 100:30 for U.S.A. This shows that in our case a waste containing higher nitrogen content can be mixed up with the domestic waste water and be treated satisfactorily.

The daily per capita contribution of chlorides in the present study agrees with that reported by others (6), (22).

The per capita contribution of BOD is perhaps the most important parameter in the design of wastewater treatment and assessing population equivalent for industries. This value was found to be 0.12 lb/cap/day in this study. It is observed that it is higher than those reported for some other places in India which lie in the range of 0.06-0.1 lb/cap/day (2),(42). The present value is in better agreement with those reported in U.K. and U.S.A. as cited in Chapter 2. The reason for a high per capita BOD is that consumption and wastage of food stuff in the hostel is more than that in an average indian community.

4.3 Effect of Temperature on BOD Rate Constant

Effect of temperature on BOD rate constant was studied by standard BOD technique and Warburg respirometer. The results are discussed in following sections.

4.3.1 Study by Standard BOD Technique

Observed BOD values used to calculate the rate constant at different temperatures are listed in Table 5. The rate constants are calculated according to Fujimoto's method, Appendix A. It is seen that the rate constant at 35°C for the five samples lies in the range of .27-.31/day. It may be concluded from the observation that the waste

characterstics as far as the biodegrability of organic matter is concerned did not change on the different days of sampling. Therefore it is assumed that the variation in rate constants when samples collected on different days were incubated at different temperatures reflects only the effect of temperature.

TABLE 5

BOD PROGRESSION AT DIFFERENT TEMPERATURES

Days	Sample I		Sample II		Sample III		Sample IV		Sample V	
	35°C	30°C	35°C	40°C	35°C	20°C	35°C	10°C	35°C	45°C
1	103	97	106	95	95	70	90	0	50	10
2	153	144	163	140	142	105	138	9.5	75	45
3	175	166	185	176	167	130	152	12.5	85	65
4	180	175	208	195	172	148	180	28.4	105	90
5	189	185	218	210	182	159	186	45.5	110	100
6	195	190	230	222	185	168	190	60	110	110
L_o	198	195	233	237	192	180	192	185	113	130
K	0.31	0.27	0.27	0.19	0.31	0.17	0.29	0.05	0.27	0.13

6 Figures 5 and 6 show the data of Table 5 plotted as percent of ultimate BOD satisfied versus time. The curves in these figures correspond to first order reactions having respective values of the rate constants shown in Table 5. The curve and data for 35°C are plotted on the basis of mean of the five values. In the case of incubation temperature of 10°C there was a lag of two days in exertion of oxygen demand. Therefore while calculating the value of rate constant the first two observation

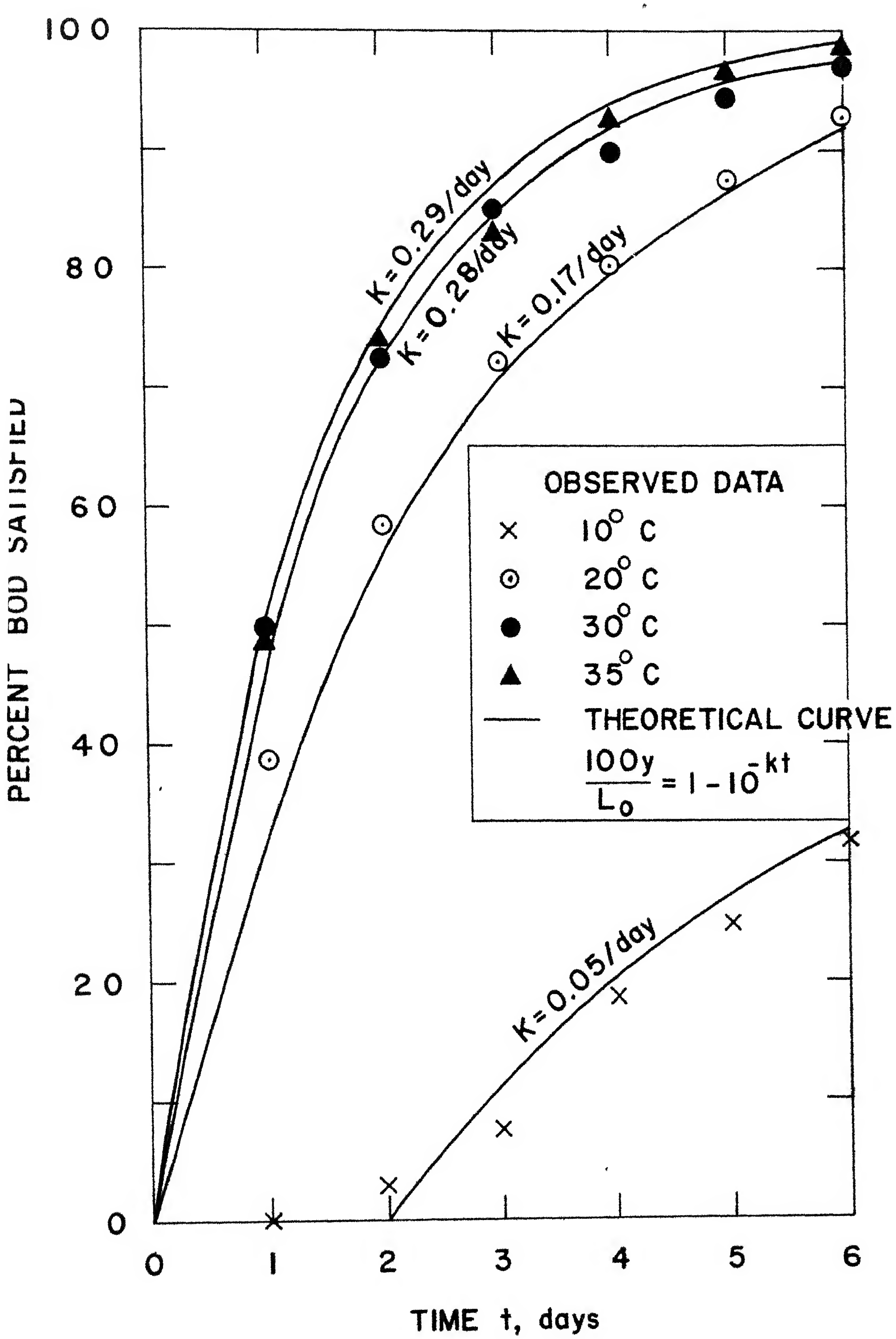


FIG. 5 BOD PROGRESSION WITH TIME AT 10, 20, 30 & 35°C (STANDARD BOD TECHNIQUE)

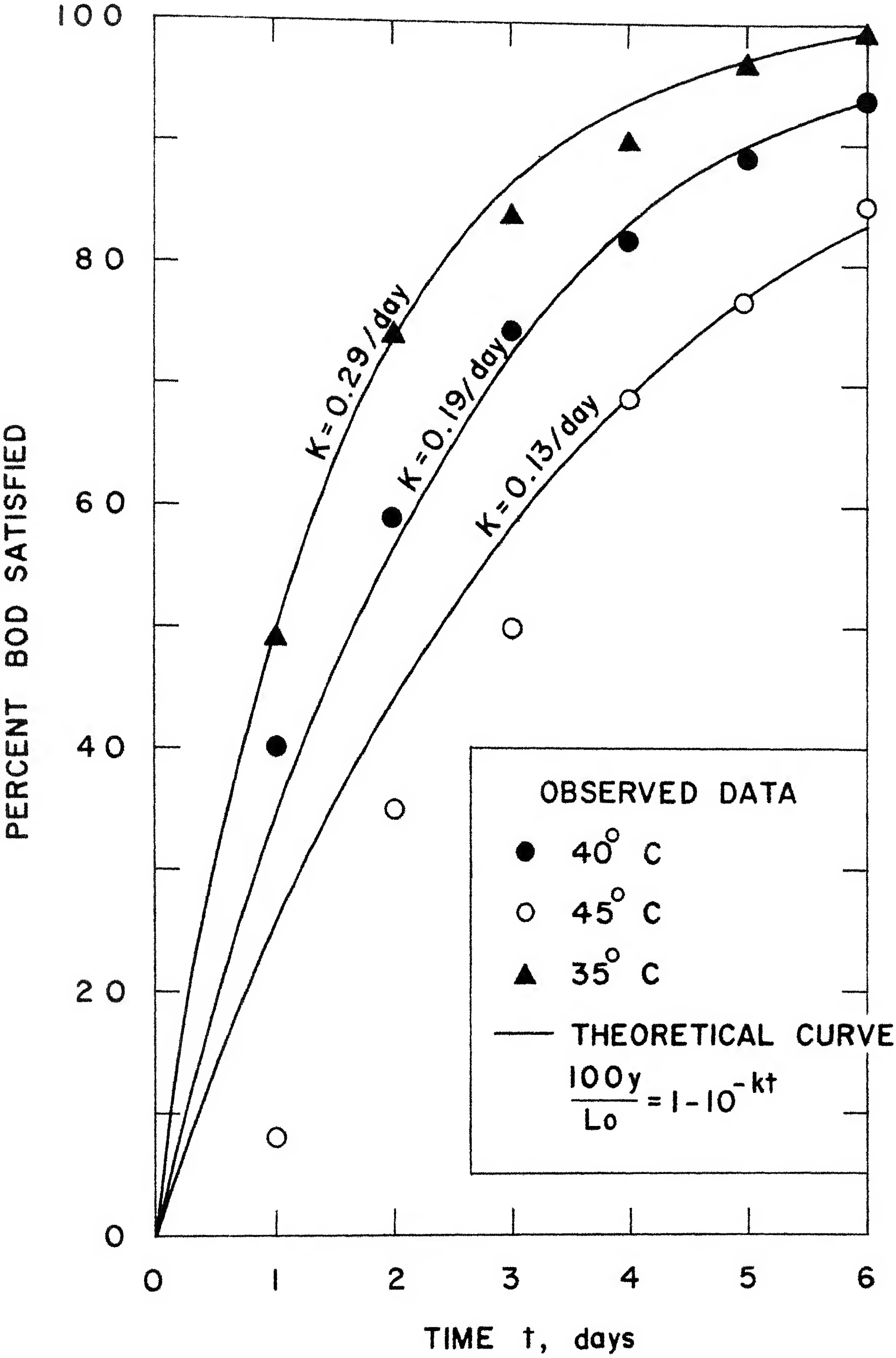


FIG. 6 BOD PROGRESSION WITH TIME AT 40, 45 & 35°C
(STANDARD BOD TECHNIQUE)

were neglected. It is seen from Table 5 and Figures 5 and 6 that the rate constant increased with increasing temperature up to 35°C and then started decreasing.

To obtain a relationship between value of K and temperature the data is plotted according to the following equation:

$$\frac{K_2}{K_1} = \theta^{T_2 - T_1} \qquad \ldots\ldots\ldots\ldots\ldots 2.2.4$$

The data and the theoretical plot is shown in the Figure 7. It is observed that rate constant increases with increase in temperature in the range of 10- 4.5°C at a decreasing rate. This is expected as θ which has been assumed to be constant actually charges slightly with change in temperature. Rate constant starts decreasing above a temperature of 34.5°C. The reason for this is inactiviation of enzymes catalyzing the biochemical reactions(43). Gotaas (24) observed that rate constant starts decreasing ofter 30°C and attributed it to decrease in the activity of mesophilic bacteria after 30°C. This was confirmed by Arceiwala and Gajendragadkar (2) Bewtra and Radha Charan (1) observed that it decreases after 37°C.

From the observations it is seen that three curves can be drawn with the help of observed data. The equations of these curves are as follows:

$$\text{for } 10\text{–}20^\circ C \quad , \; K_T = K_{20} \; 1.1126^{T-20} \quad \ldots\ldots \; 4.3.1.1$$

$$\text{for } 20\text{–}35^\circ C \quad , \; K_T = K_{20} \; 1.042^{T-20} \quad \ldots\ldots \; 4.3.1.2$$

$$\text{for } 35\text{–}45^\circ C \quad , \; K_T = K_{35} \; 0.9226^{T-35} \quad \ldots\ldots \; 4.3.1.3$$

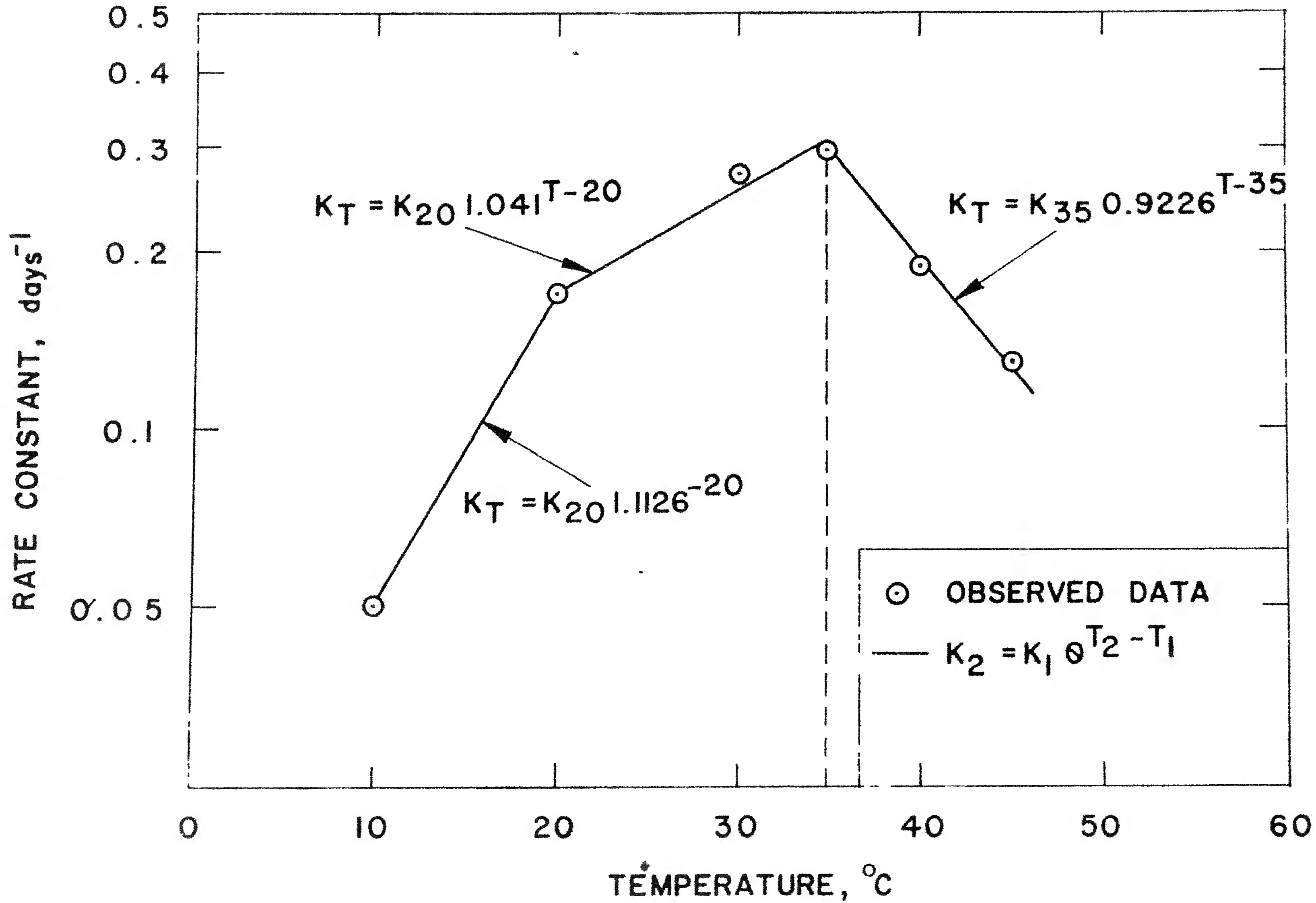


FIG.7 RELATIONSHIP BETWEEN TEMPERATURE AND BOD RATE CONSTANT (STANDARD BOD TECHNIQUE)

Bewtra and Radhacharan (1) have found out similar equation listed below:

for 5-15°C, $K_T = K_{20}\ 1\text{-}108^{T-20}$ 4.3.1.4

for 15-40°C, $K_T = K_{20}\ 1.041^{T-20}$ 4.3.1.5

for 30-40°C, $K_T = K_{20}\ 0.9657^{T-20}$ 4.3.1.6

It is seen that in the present study the value of θ in the frequently used range of 20-35°C compares well with the values reported by other investigators (1), (24), (29).

The observed value of rate constant at 20°C, K_{20} is 0.17/day which is consistant with the values reported by others (1), (3), (24), (25), (26).

Fair and Geyer (11) reported the activation energy E of the BOD reactio to be 7900 Cal in the temperature range of 15-30°C. Considering the values o rate constant at 20 and 30°C in the present study it has been found to be 8800 cal which is in agreement with the value reported by Fair and Geyer.

4.3.2 Study by Warburg Respirometer

Figures 8 and 9 show the results of study using Warburg respirometer. The data has been obtained in the same manner as that for standard BOD technique. It is seen from Figure 8 and 9 that when observations are taken over short period of time (hours) there is a greater divergence between the theoretical and observed values. Figure 10 shows the relationship between the change in rate constant with change in temperature. The two curves describi the relationship are as follows:

for 20-36°C, $K_T = K_{20}\ 1.042^{T-20}$ 4.3.2.1

for 36-45°C, $K_T = K_{36}\ 0.8626^{T-36}$ 4.3.2.2

The value of θ in the range of 20-36°C is again seen to be consisten with that reported by others. The value of rate constant at 35°C from this data is approximately double the value of rate constant at 20°C. Similar ratio of K values at 35°C and 20°C has been reported by Tool (39).

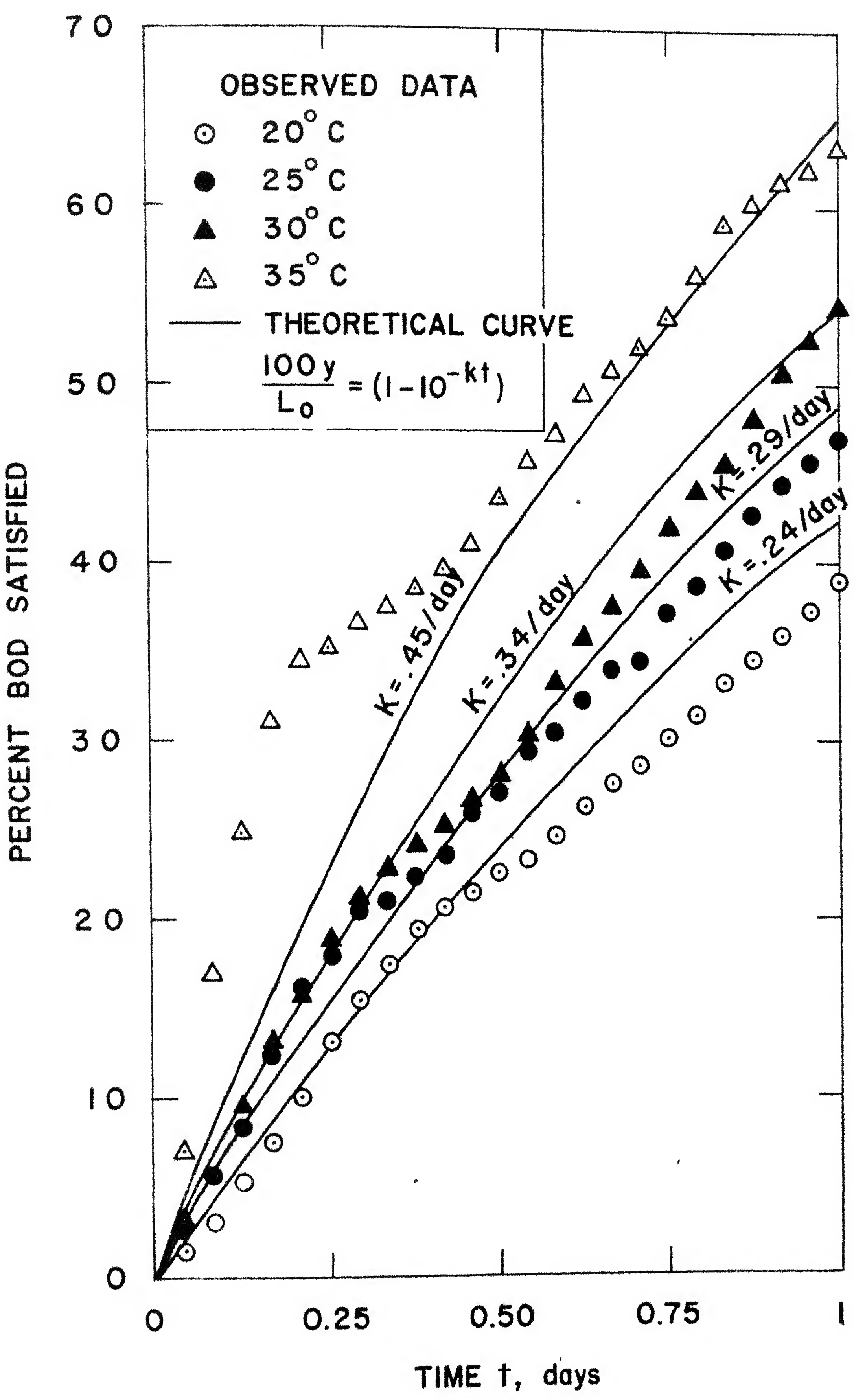


FIG. 8 BOD PROGRESSION WITH TIME AT 20, 25, 30 & 35°

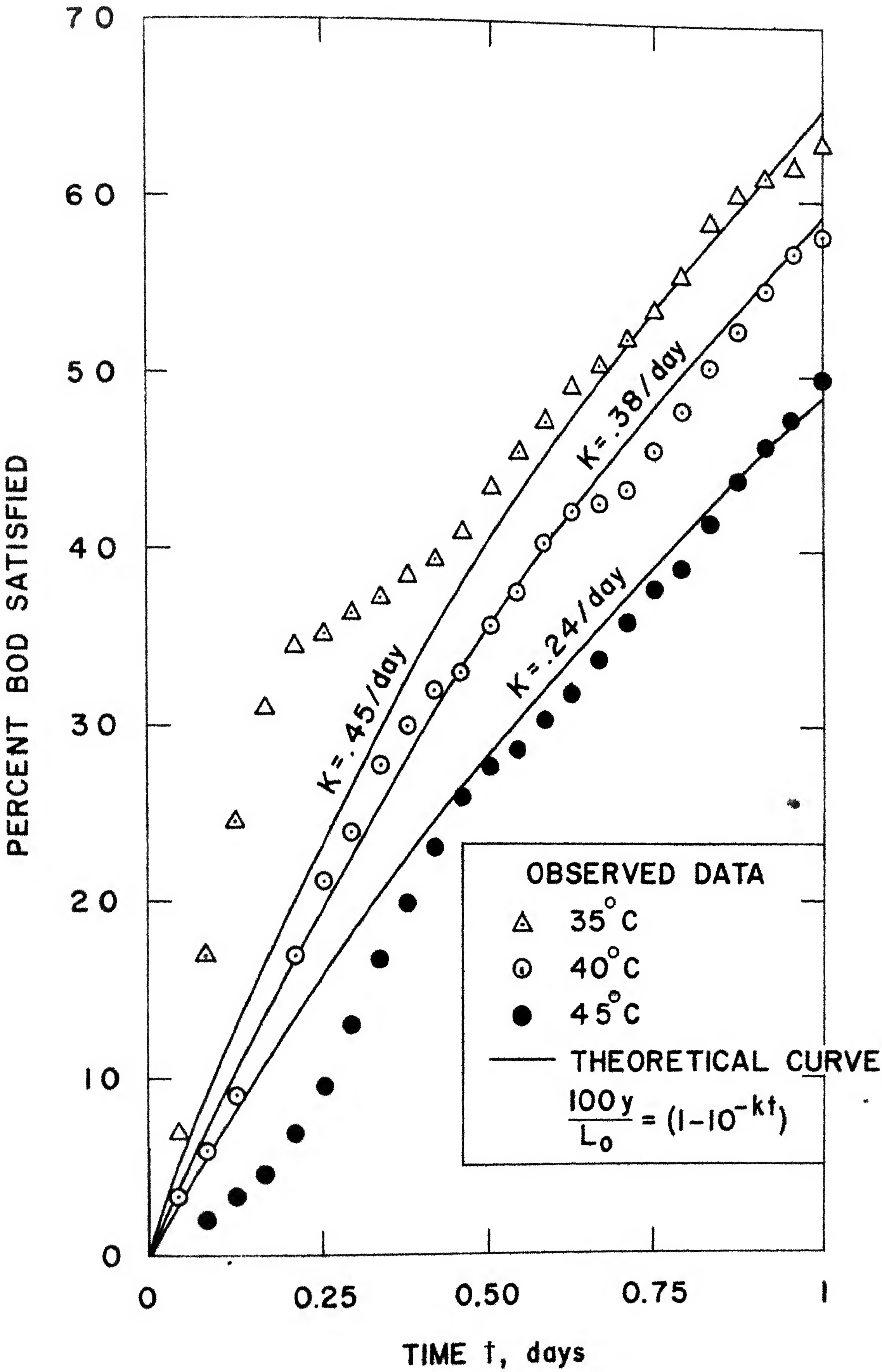


FIG. 9 BOD PROGRESSION WITH TIME AT 35,40 & 45°C
(BY WARBURG RESPIROMETER)

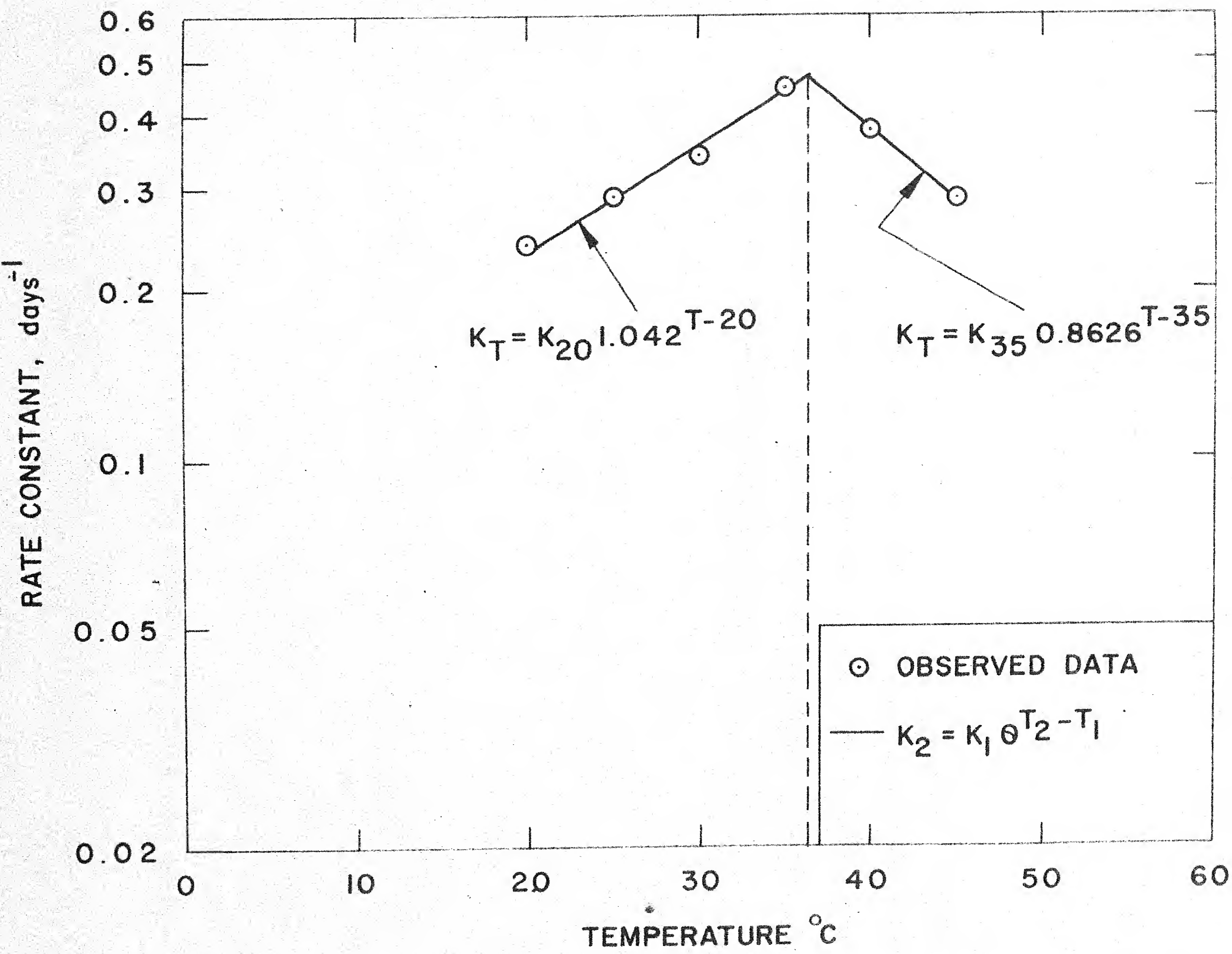


FIG. 10 RELATIONSHIP BETWEEN TEMPERATURE AND BOD RATE CONSTANT (BY WARBURG RESPIROMETER)

Values of rate constant determined by Warburg method are approximately 50 percent higher than those obtained by conventional BOD method. Lee (32) and Gellman (36) have reported rate constant values by Warburg to be 15 percent higher than that by conventional method. The higher difference in the present case may be due to the fact that the test was run for 24 hours only during which rate constant may be higher as compared to subsequent period.

It is observed from the BOD progression curves that it does not follow a smooth curve. Instead after 4-8 hours there is decrease in the reaction rate for some time, after which it proceeds with different rate. This fact shows that the assumption that BOD progression is first order reaction is only approximately true.

5. CONCLUSIONS

The study carried out on the wastewater from hostel IV of Indian Institute of Technology, Kanpur has revealed the following:

1. The average wastewater flow per capita was 128 gallons/day.
2. The ratio of maximum and minimum flows to average flow was found to be 1.8 and 0.6 respectively.
3. The per capita contribution of various constituents in the wastewater was as follows:

Total Solids	0.16 lbs/day
Dissolved Solids	0.07 (36% Volatile) lbs/day
Suspended Solids	0.09 (18% Volatile) lbs/day
Ammonia Nitrogen	0.0047 lbs/day
Organic Nitrogen	0.0085 lbs/day
Total Phosphate	0.003 lbs/day
Chlorides	0.014 lbs/day
5-day, 20°C BOD	0.12 lbs/day

4. The 5-day, 20°C BOD of the wastewater was found to be 115 mg/l (which corresponds to 0.12 lbs/cap/day. The BOD reaction has a rate constant(K_{20}) equal to 0.17/day.
5. Ultimate, 20°C BOD was found to be 56 percent of the COD value.
6. Variation of the rate constant with temperature followed the following relationships:

Standard BOD method

for 10-20°C , $K_T = K_{20} \; 1.1126^{T-20}$ 4.3.1.1

for 20-35°C , $K_T = K_{20} \; 1.042^{T-20}$ 4.3.1.2

for 35-45°C , $K_T = K_{35} \; 0.9226^{T-35}$ 4.3.1.3

Warburg Method

for 20–36°C, $K_T = K_{20}\ 1.042^{T-20}$ 4.3.2.1

for 36–45°C, $K_T = K_{36}\ 0.8626^{T-36}$ 4.3.2.2

7. BOD rate - constent increases with rise in temperature upto 35°C and above it the rate constant starts decreasing.

BIBILOGRAPHY

1. Bewtra, J.K. and Charan, R., "Effect of Temperature on Biochemical Oxygen Demand", Environmental Health, 7 : 143(1965).

2. Arceivala, S.J. and Gajendragadkar, S.K., "Studies on BOD of Sewage at Bombay", Proce. Symp. Water Pollution Control, Dec. 28-30, 1965, CPHERI, Nagpur.

3. Thergonkar, V.P., Determination of Rate Constant K in the Biochemical Oxidation of Ahmedabad Sewage Samples at 20°C", Environmental Health, 5 : 250(1963).

4. "Standard Methods for the Examination of Water, Sewage and Industrial Wastes", 12th Edition (APHA, AWWA and WPCF, New York), 1965.

5. Metcalf, L. and Eddy, H.P., "Sewerage and Sewage Disposal", McGraw-Hill Book Co., Inc., Newyork, 1930.

6. Sawyer, C.N., "Chemistry for Sanitary Engineers", McGraw-Hill Book Co., Inc., Newyork, 1960.

7. Gharpure, V.N., "A Text Book of Sanitary Engineering", Engineering Book Co., Poona, 1961.

8. Ray, P and David, A., "Effect of Industrial Wastes and Sewage upon the Chemical and Biological Composition and Fisheries of the River Ganges at Kanpur (U.P.)", Environmental Health, 8 : 310(1966).

9. Babbitt, H.E., and Baumann, E.R., "Sewerage and Sewage Treatment", Asia Publishing House, Bombay, 1960.

10. Sharma, L.N., Bewtra, J.K., and Nagpal, J.L., "Charactersties of Suspended Solids in Okhla Sewage", Proc. Symp. Water Pollution Control, Dec. 28-30, 1965, CPHERI, Nagpur.

11. Steel, E.W., "Water Supply and Sewerage", McGraw-Hill Book Co., Inc., Newyork, 1960.

12. Kshirsagar, S.R., "Sewerage and Sewage Treatment", Roorkee Publishing House, Civil Lines, Roorkee, 1965.

13. Deshpande, R.S., "A Text Book of Sanitary Engineering", United Book Corporation, Poona, 1963.

14. Kothandraman, V., "Physico-chemical and Biological Aspects of Ahmedabad Sewage", Environmental Health 5 : 357(1963).

15. Eckenfelder, Jr, W.W. and O'connor, D.J., "Biological Waste Treatment", Pergaman press, Oxford, 1961.

16. Fruh, E.G., "Overall Picture of Entrophication", J.W.P.C.P., 39 : 1449(1967)

17. Sawyer, C.N., "Phosphates and Lake Fertlization", Sewage and Industrial Wastes, 24 : 768(1952).

18. Moore, E.W., "Simplified Methods for Analysis of BOD Data", Sewage and Industrial Wastes, 22 : 1343(1950).

19. Thomas, Jr, H.A., "Graphical Determination of BOD Curve Constants", Water and Sewage Works, 97 : 123(1950).

20. Fujimoto, Y.J., "Graphical Use of First Stage BOD Equation", JWPCF, 36 : 69(1964).

21. Bagchi, D. and Chaudhary, N., "Simplified Method for Determination of BOD Constants", Proc.Symp. Water Pollution Control, Dec.28-30, 1965 CPHERI, Nagpur.

22. Fair, G.M. and Geyer, J.C., "Water Supply and Waste Water Disposal", John Wiley and Sons, Inc., Newyork, 1961.

23. Boltman, R.L. and Klein, L., "Sewage Treatment Basic Principles and Trends", Butterworths Scientific Publications, London, 1961.

24. Gotaas, H.B.,"Effect of Temperature on Biochemical Oxygen Demand", Sewage Works Journal, 20 : 441(1948).

25. Moore, W.A. and Ruchoft, C.C., "Chemical Oxygen Demand and its Relationship to BOD", Sewage and Industrial Wastes, 23 : 705(1951).

26. Streeter, H.W. and Phelps E.B., " A Study of the Pollution and Natural Purification of the Ohio River, III", U.S. Public Health Bulletin No. 146, 1925.

27. Thiman, K.V., "The Life of Bacteria", The Macmilan Companey Newyork,1960.

28. Barbar, M.A., Journal of Infections diseases, 5 : 379, 1908.

29. Phelps, E.B., "Stream Sanitation", John Wiley and Sons, Newyork, 1953.

30. Theriautt, E.J., "The Oxygen Demand of Polluted Waters", U.S.P.H.S. Bulletin 173, 1927.

31. Young, J.C. and Clark, J.W., "History of Biochemical Oxygen Demand Test", Water and Sewage Works, 112 : 81(1965).

32. Lee, E.W. and Oswald, W.J., "Comparative Studies of the Dilution and Warburg Method for Determining BOD", Sewage and Industrial Wastes, 26 : 1097(1954) .

33. Caldwell, D.H. and Langelier, W.F., "Manometric Measurements of BOD of Sewage", Sewage Works Journal, 20 : 202(1948).

34. Falk, L.L. and Rudolfs, W., "Factors Effecting the Direct Oxygen Utilization Method", Sewage Works Journal, 19 : 1000(1947).

35. Heukelkian, H., "Use of Direct Method of Oxygen Utilization in Waste Treatment Studies", Sewage Works Journal, 19 : 875(1947).

36. Gellman, I. and Heukelkian, H., "Studies of Biochemical Oxidation by Direct Methods I Direct Method for Determining BOD", Sewage and Industrial Wastes, 23 : 1267(1951).

37. Heukelkian, H., "The Use of Dilution Method for Determining the Effect of Industrial Wastes on Deoxygenation", Sewage Works Journal, 19: 612 (1947).

38. Standard Methods, 11th Edition (APHA, AWWA and WPCF, New York), 1961.

39. Tool, H.R., "Manometric Measurements of BOD", Water and Sewage Works, 114 : 211 (1967).

40. "Report on National Water Supply and Sanitation Schemes", Committee on Plan Projects, New Delhi, June 1961.

41. Wilke, H.R., "A Report on Campus Water Supply", IIT/Kanpur, Sept. 1965.

42. Rangnathan, G., "Studies on Madras City Sewage System", Thesis Submitted to Madras University, 1957.

43. Conn, E.E. and Stumpf, E.E., "Outlines of Biochemistry", John Wiley and Sons, Inc., Newyork, 1966.

APPENDIX A

FUJIMOTO'S METHOD FOR DETERMINATION OF BOD RATE CONSTANT AND ULTIMATE BOD

Determination of BOD Rate Constant and Ultimate BOD for Sample I at 35°C

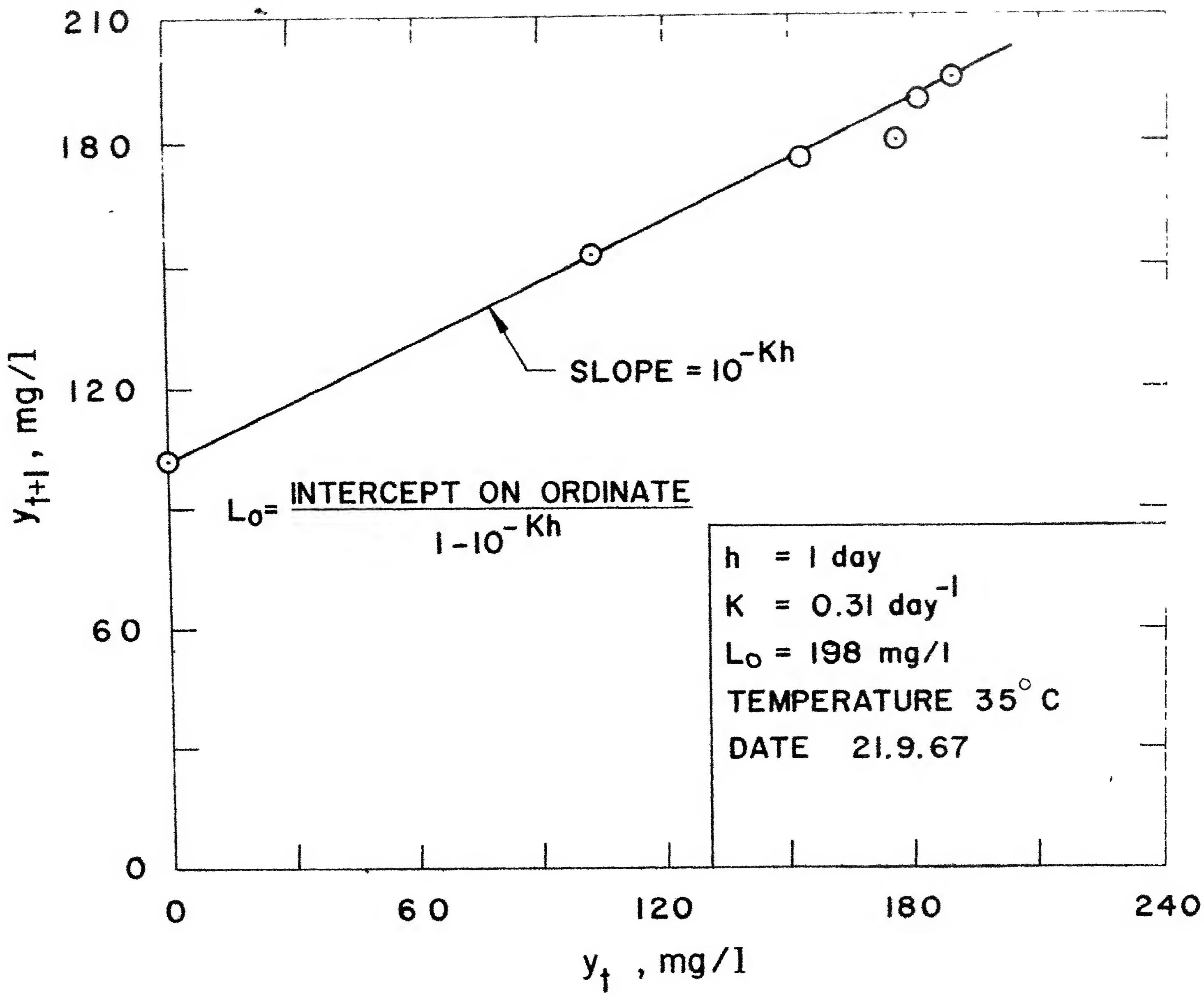


FIG. 11 DETERMINATION OF BOD RATE CONSTANT BY FUJIMOTO'S

APPENDIX B

LIST OF ABBREVIATIONS

Biochemical Oxygen Demand	BOD
centimeter(s)	cm
Chemical Oxygen Demand	COD
gallons per capita per day	gpcd
gallons per day	gpd
gallons per hour	gph
milligrams per liter	mg/l
milliliter(s)	ml
Normal Temperature and Pressure	NTP